Analysis

Using Bibliometric Analysis to Understand the Recent Progress in Agroecosystem Services Research

Wenjing Liu[a], Jingsheng Wang[b,*], Chao Li[b], Baoxiong Chen[c], Yufang Sun[c]

[a] School of Environment and Natural Resources, Renmin University of China, Beijing 100872, PR China
[b] Qianyanzhou Ecological Research Station, Key Laboratory of Ecosystem Network Observation and Modelling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, PR China
[c] Rural Energy & Environment Agency, Ministry of Agriculture of the People's Republic of China, Beijing 100125, PR China

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ABSTRACT

As a semi-natural ecosystem, the agroecosystem is both a major provider and a major beneficiary of ecosystem services (ES). The aim of this paper was to contribute to the scientific understanding of the current status of AES research, recognize the knowledge base and influential articles, and uncover the key research themes and how the research themes have evolved over the past decade. Bibliometric methods based on the ISI Web of Science (WoS) database were used to analyse articles related to AES published between 2008 and 2017. A total of 3573 records were evaluated during this study. The results show that there has been a significant increase in research interest in the AES field. The most frequent keywords were "Biodiversity", "Land use change" and "Climate change". This study divides the common keywords into 7 categories and analyses them over two periods. Agrobiodiversity and land use have been emphasized in current AES research, which is a trend that will likely continue in the future. Valuation is indispensable, but AES research has needs beyond monetary valuation. In the future, multisubject and multimethod integrative research for understanding, modelling, evaluating, and managing the AES will be more abundant.

1. Introduction

Numerous resources and processes supplied by natural ecosystems, such as food production, climate control, nutrient cycles and spiritual benefits, provide the foundations of human existence (Costanza et al., 1997; Kremen, 2005). In general, these benefits are known as "ecosystem services". Ecosystem services (ES) were defined by Daily as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life" (Daily, 1997). Similarly, Costanza et al. (1997) defined ES as the benefits that humans directly or indirectly derive from ecosystem functions, which include ecosystem goods and services. The United Nations 2004 Millennium Ecosystem Assessment (MA) was a highlight in ES research. The MA (Millennium Ecosystem Assessment, 2005) defined ES as "the benefits people obtain from ecosystems", including provisioning services, regulating services, cultural services and supporting services. Since then, the Economics of Ecosystems and Biodiversity (TEEB) group noted that the MA framework did not pay very much attention to economic issues, and they proposed a new framework to include the provisioning services, regulating services, habitat or supporting services and cultural

services (TEEB, 2010). In conclusion, ES are "the ecological characteristics, functions, or processes that directly or indirectly contribute to human wellbeing: that is, the benefits that people derive from functioning ecosystems" (Costanza et al., 2017).

Agroecosystems are an important component of terrestrial ecosystems that occupied 37.27% of the land area in 2015 (The World Bank Group, 2015), and they play an ongoing and important role in human social development. As a semi-natural ecosystem, the agroecosystem is both a major provider to and a major beneficiary of ES (Garbach et al., 2014). Agricultural ecosystems not only provide for the most basic needs of human beings, such as food, energy and pharmaceuticals, but they also provide a variety of ES, such as soil and water quality regulation, climate regulation, biodiversity support and tourism services (Power, 2010; Zhang et al., 2007). Compared with other ecosystems, the crop production function of the agroecosystem has intensified while impairing other ES such as soil conservation, pest control and biodiversity maintenance (Bianchi et al., 2006; Gallai et al., 2009; Power, 2010; Tscharntke et al., 2012). These perspectives have resulted in increasing focus on agroecosystem services (AES) across the world, and there are many related studies on the various aspects of AES that have

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been published in international journals in recent years. For example, some publications have focused on describing, classifying and performing comprehensive assessments of AES (Dominati et al., 2010; Swinton et al., 2007; Zhang et al., 2007), other studies explore the interactions between biodiversity, land use and AES (Barrios, 2007; Sun and Li, 2017; Swift et al., 2004), and others have analysed the impacts of agricultural practices, management and decision-making on AES (Bateman et al., 2013; Dale and Polasky, 2007; Xu et al., 2018). Moreover, as complex ecological and economic systems, human agricultural activities have become a dominant force that directly affects the sustainable development of human social activities. Therefore, some governments and organizations have called on multifunctional agriculture to maximum the synthesized benefits. In these situations, the AES has become an interdisciplinary problem that involves various relationships among the economy, society and ecology. As a consequence, there has been rapid growth in AES-related research in recent years (Tancoigne et al., 2014).

The increase in AES-related research led us to investigate how the ES concept is applied in the agriculture field. Bibliometric studies employing the quantitative analysis of the literature has recently gained importance because it can provide new perspectives about the knowledge status and trends in a given field (Aleixandre-Benavent et al., 2017; Liu and Gui, 2016; Wei et al., 2017). Currently, there are a number of scientific articles involving the bibliometric method to reveal the characteristics and identify the research themes regarding ES research around the world (Blouin et al., 2013; Kull et al., 2015; Liu and Liu, 2015; Wu and Wang, 2018). However, to the best of our knowledge, few studies in the field of AES have employed bibliometric methods. He et al. (2018) used CiteSpace information visualization software to survey the literature on agricultural ecological compensation and Tancoigne et al. (2014) discussed the place of agricultural sciences in the ES field. To fill this research gap, this paper investigates the performances of AES-related articles published from 2008 to 2017 using the bibliometric method. The goals of this study include the following: (1) to identify the popular journals, representative countries, influential scholars and primary research subjects in the AES research field; (2) to recognize the knowledge base and influential articles of AES field in the past decade; and (3) to uncover the key research themes and how they have evolved over the past decade.

This paper is organized as follows. After this introduction, the primary research methods and materials are provided in Section 2. The research findings and analyses are presented in Section 3. Section 4 discusses the characteristics of these studies and provides self-reflection on this study. Finally, Section 5 presents research-related conclusions.

2. Methods and Materials

2.1. Bibliometric Analysis

Bibliometrics is a form of statistical analysis that can be used to analyse academic literature quantitatively. In recent years, numerous publications have used bibliometric analyses to offer innovative perspectives on evaluating research trends (Ellegaard and Wallin, 2015). The statistical analysis (including journals, authors, countries and institutions) can help the people who are interested in a field to grasp the basic information and development status of the literature quickly. Furthermore, one commonly used bibliometric method is citation analysis. Based on the premise that heavily cited articles are likely to have a greater influence on the research field, analysis of the citations can provide useful information about the journals, papers, and authors that can be considered influential (Pilkington and Meredith, 2009). A co-citation analysis is defined as the frequency with which two documents are cited together by other documents (Small, 1973). Co-citation analyses allow researchers to recognize the inherent relationships in the literature and identify the core publications/citations and the major knowledge groups of a field (Pilkington and Meredith, 2009). In addition, graphing and visualizing bibliometrics can illustrate the relationship among an analytical unit in a more intuitive way.

2.2. Tools

Bibexcel is a free tool-box developed by Olle Persson, and it can assist in analysing bibliographic data downloaded from Web of Science or Scopus (Persson et al., 2009). Bibexcel can perform the basic bibliometric analysis, citation analysis, co-citation, bibliographic coupling and other functions. Bibexcel can also produce net-files for co-occurrence analysis, and then they can be mapped by Pajek, NetDraw or Gephi for further analysis. More information about Bibexcel can be found at http://homepage.univie.ac.at/juan.gorraiz/bibexcel/. Gephi is also open-source and free software, and it can compute and visualize the network. More information about it can be found at https://gephi.org/.

2.3. Data Sources and Processing

The ISI Web of Science (WoS) is currently one of the primary sources for citation data (Mongeon and Paul-Hus, 2016). The ISI Web of Science Core Collection (WoSCC) database is an influential, interdisciplinary, periodical, full-text database that provides deep coverage and a comprehensive index of the journals, books, and proceedings of the social sciences, natural sciences, arts and humanities, etc. Thus, the data for this study were collected from the WoSCC database. As shown in Fig. 1, the keywords "agroecosystem-*-service*" (including "agroecosystem service", "agroecosystem services", "multiple agroecosystem services", et al.), "agro-ecosystem-*-service*" (including "agro-ecosystem service", "agro ecosystem service", "agro-ecosystem services", et al.) and "agricultur*" and "ecosystem-*-service*" (including "agriculture" and "ecosystem services", "agricultural" and "ecosystem services", et al.) were used as search parameters in the "topic" (including the article title, abstract, keywords and keywords plus) field. To clarify the type of data, we selected "article" from the "document types" option and "English" in the "languages" option for further analysis in this paper. After the TEEB project was proposed by Germany in 2007, ES have attracted more attention with respect to the economic aspects of ES research (Costanza et al., 2017). Since then, ES-related studies may have become more diverse. Accordingly, the data span of this study is from 2008 to 2017. A total of 3573 publications were selected on June 10, 2018.

3. Results and Analyses

3.1. Overview of the Publication Characteristics

As shown in Fig. 2, the number of annual publications exhibited an increasing trend from 2008 to 2017. The number of annual publications increased from 73 in 2008 to 730 in 2017. The number of publication on AES has increased ten-fold in the last decade. The increasing publication trend indicates that AES fields have received increasing attention. It can be predicted from the present trend that the number of publications related to this study will continue to grow rapidly. To investigate the influence of the AES field and its developmental state, this study analyses the popular journals, representative countries, influential authors and subject distribution.

3.1.1. Primary Analyses of Different Journals

A total of 614 journals published articles relevant to AES research from 2008 to 2017. Table 1 shows the top 10 most popular journals. *Agriculture, Ecosystems & Environment* (208) was the most popular journal, followed by *Land Use Policy* (127), *PLOS ONE* (106) and *Ecological Economics* (86). During this period, *Agriculture, Ecosystems & Environment* not only published the most articles but also was the most frequently cited journal with 3255 total citations.
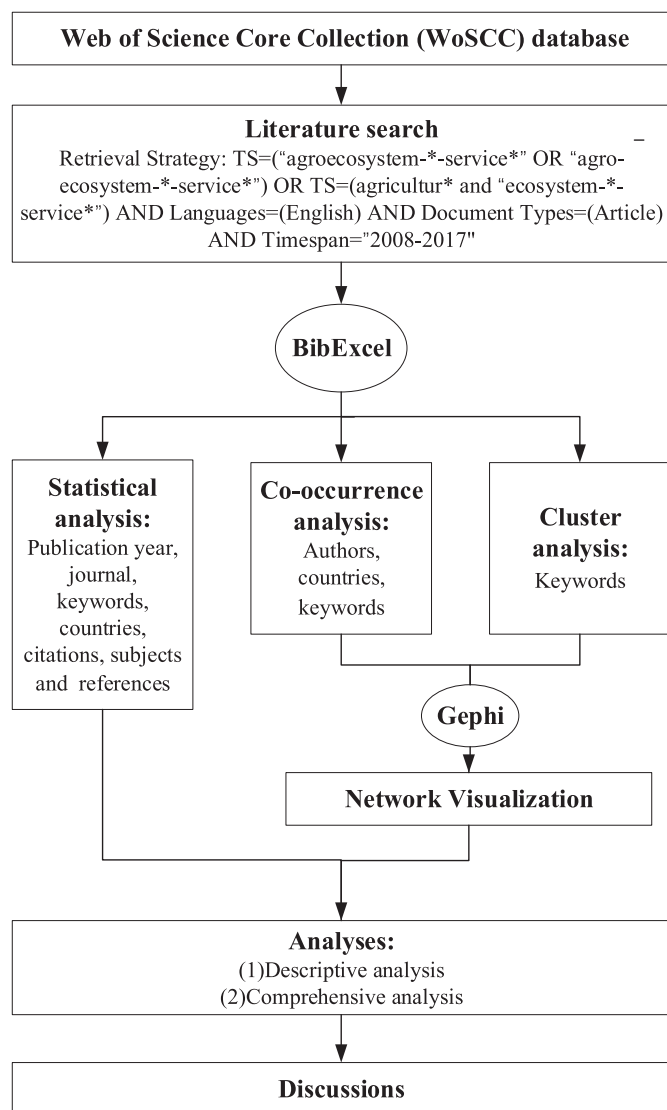
Web of Science Core Collection (WoSCC) database

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Literature search
Retrieval Strategy: TS=("agroecosystem-*-service*" OR "agro-ecosystem-*-service*") OR TS=(agricultur* and "ecosystem-*-service*") AND Languages=(English) AND Document Types=(Article) AND Timespan="2008-2017"

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BibExcel

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Statistical analysis:
Publication year, journal, keywords, countries, citations, subjects and references

Co-occurrence analysis:
Authors, countries, keywords

Cluster analysis:
Keywords

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Gephi

↓

Network Visualization

↓

Analyses:
(1)Descriptive analysis
(2)Comprehensive analysis

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Discussions

Fig. 1. The general flow diagram for systematic bibliometric analyses. The Search Rules of WoS can be found at http://images.webofknowledge.com//WOKRS529MR9/help/WOK/hs_search_rules.html.

Table 1
The performance of the 10 most popular journals. The impact factors were taken from the Journal Citation Report (JCR) published in 2017.

TP	Percentage	Journal	TC	Impact factor (2016)	*h*-index
208	5.92%	Agriculture, Ecosystems & Environment	3255	3.541	30
127	3.62%	Land Use Policy	1751	3.194	23
106	3.03%	PLOS ONE	1875	2.766	24
86	2.42%	Ecological Economics	2551	3.895	25
85	2.50%	Ecosystem Services	818	4.395	17
79	1.97%	Journal of Applied Ecology	2850	5.742	31
77	2.00%	Biological Conservation	2605	4.660	25
71	2.09%	Ecological Indicators	1220	3.983	19
65	1.83%	Journal of Environmental Management	941	5.005	19
64	1.80%	Ecology Applications	1779	4.393	24

TP: the number of publications; TC: total citations of a journal.

The impact factor (IF) is a measure of the relative importance of a journal within its field, and the journals with higher IF values were deemed to be more important than those with lower ones (Garfield, 2006). The *h*-index is an author influence metric that considers both the productivity and the citation impact of the publications by an author (Hirsch, 2005). For now, the *h*-index can also be applied to assess the influence of a journal or a country on a specific field (Li and Zhao, 2015). In this study, the *Journal of Applied Ecology* has the highest IF (5.742) and *h*-index (31) among the top 10 most popular journals. The *Journal of Environmental Management* has the second-highest IF (5.005) among the top 10 most popular journals, but its *h*-index is much lower than those of the *Journal of Applied Ecology* and *Agriculture* or *Ecosystems & Environment*.

3.1.2. Primary Analyses of Different Countries/Territories

In the 2008–2017 period, a total of 125 countries/territories published AES-related articles. As shown in Fig. 3, there are 14 countries/territories that have published more than 100 articles. Among these countries, the USA (1227, 34.34%) published the most articles, followed by the UK (569, 15.92%) and Germany (476, 13.32%). These three countries not only published numerous articles but also had the top three *h*-indexes among the countries/territories active in this field (USA, 71; UK, 64; Germany, 59). This finding indicates that the USA, UK and Germany have paid a great deal of attention to this field, and the three countries have promoted the development and application of AES research in the past ten years. Furthermore, the Netherlands (45), Sweden (40) and Switzerland (30) have a higher *h*-index with a relatively small number of publications compared with other countries/
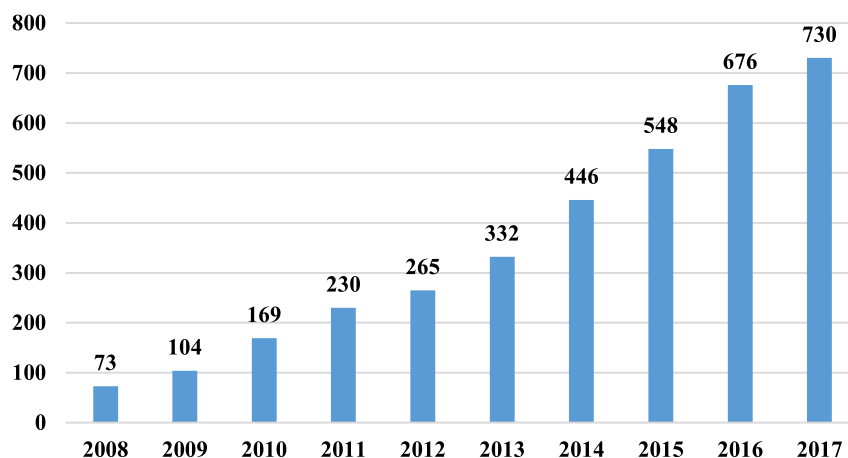
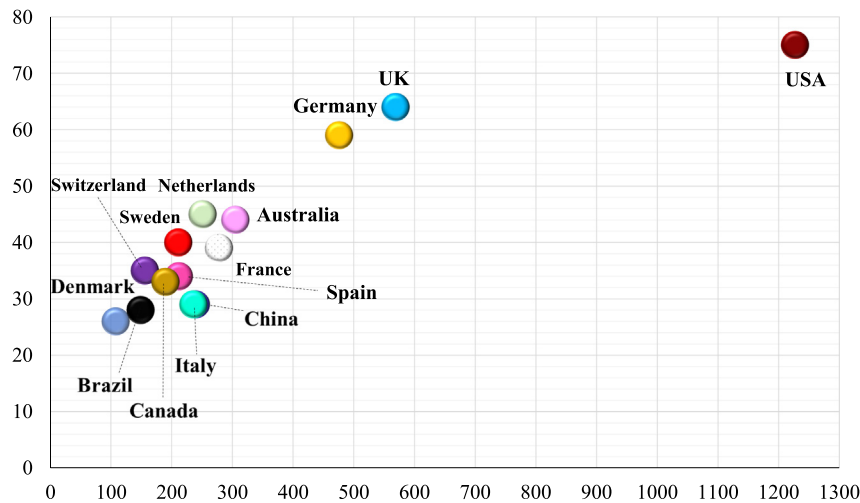Fig. 2. Annual number of publications from 2008 to 2017.

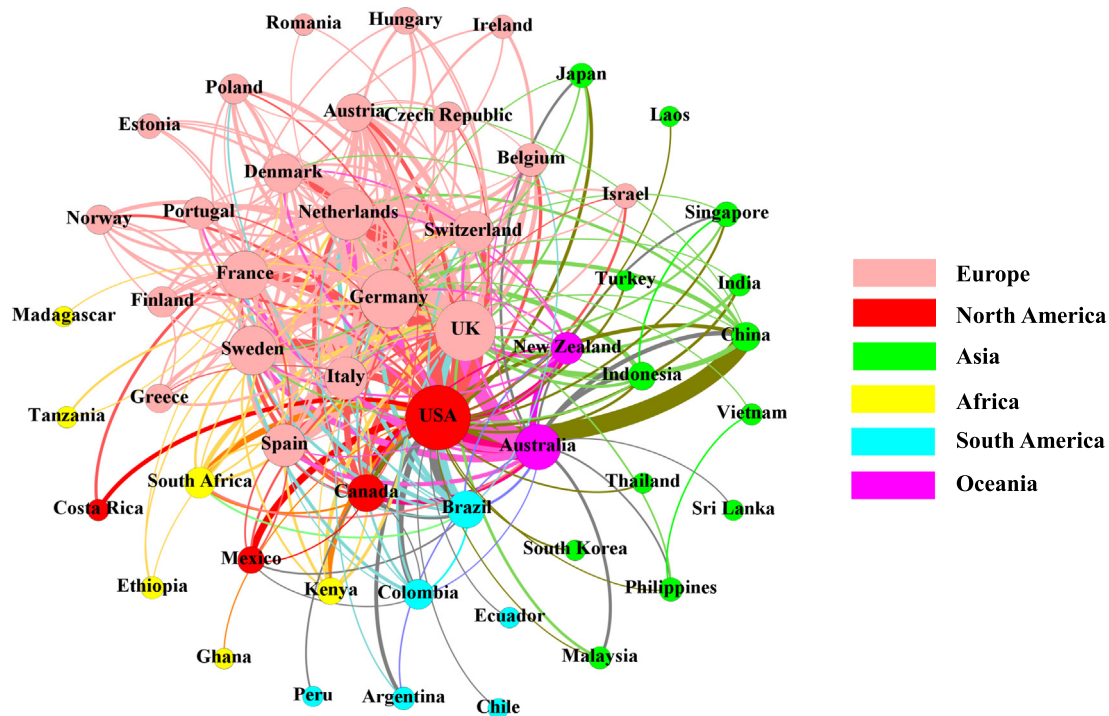**Fig. 3.** The performance of the top 14 representative countries. (TP ≥ 100).

Fig. 4. The collaboration network of the 53 representative countries/territories. (TP ≥ 10 and collaboration frequency ≥ 5).

territories. This result indicates that these countries have published some influential articles.

The academic collaborations of 53 representative countries/territories are illustrated in Fig. 4. The size of the circle represents the total collaboration frequency of the country; larger circles represent higher collaboration frequencies. Similarly, the width of the line indicates the collaboration frequency between two countries. A thicker line represents more frequent collaborations between the two countries. Among the 53 countries/territories, 22 come from Europe, 13 are from Asia, 6 come from Africa, 2 are from Oceania, 4 are from North America and 6 are from South America.

The USA is the most active country for international collaboration, especially with the UK (109 times), China (71 times), Germany (69 times) and Canada (64 times). The UK is the second-most active country, working with researchers in Germany (83 times), the Netherlands (66 times) and Australia (55 times). As shown in Fig. 4,

collaboration between research groups in European countries is quite frequent, and groups in developing countries/territories are also actively participating in collaborations. The continued expansion of collaborations in AES research will not only improve country's research abilities but also facilitate the development of this discipline.

3.1.3. Primary Analyses of Different Authors

Table 2 lists the characteristics of the 10 most influential researchers, including the h-indexes, total publications, countries, total citations, and institutions. Teja Tscharntke (25) has the highest h-index in this field, followed by Ingolf Steffan-Dewenter (22) and Claire Kremen (21). The individual analysis revealed that Teja Tscharntke is the most influential author, with 40 papers related to AES that have high citation rates. Teja Tscharntke is from the University of Goettingen, Germany. His most cited article is "*Global food security, biodiversity conservation and the future of agricultural intensification*"

Table 2
Information on the 10 most influential researchers.

Author	h-index	Country	TP	TC	Institution	Representative article	Webpages
Teja Tscharntke	25	Germany	40	3300	University of Goettingen	Global food security, biodiversity conservation and the future of agricultural intensification	https://www.uni-goettingen.de/en/92552.html
Ingolf Steffan-Dewenter	22	Germany	33	2170	University of Wuerzburg	Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance	https://www.biozentrum.uni-wuerzburg.de/en/zoo3/team/steffan-dewenter/
Claire Kremen	21	USA	33	2254	University of California, Berkeley	Modelling pollination services across agricultural landscapes	https://nature.berkeley.edu/kremenlab/
Riccardo Bommarco	20	Sweden	29	2122	Swedish University of Agricultural Sciences	Flow and stability of natural pest control services depend on complexity and crop rotation at the landscape scale	https://www.slu.se/en/cv/riccardo-bommarco/
Simon G Potts	18	UK	30	1727	University of Reading	Can arable field margins be managed to enhance their biodiversity, conservation and functional value for soil macrofauna?	http://www.reading.ac.uk/caer/caer/staff_simon_potts.html
Henrik G. Smith	17	Sweden	29	886	Lund University	Gardens benefit bees and enhance pollination in intensively managed farmland	https://www.biology.lu.se/henrik-g-smith
Peter H Verburg	17	Netherlands	37	1146	Vrije Universiteit Amsterdam	Spatial characterization of landscape functions	https://research.vu.nl/en/persons/peter-h-verburg
Claudio Gratton	16	USA	24	1127	University of Wisconsin	Landscape diversity enhances biological control of an introduced crop pest in the north-central USA	http://gratton.entomology.wisc.edu/people/claudio-gratton/
Andrea Holzschuh	15	Germany	16	1627	University of Würzburg	Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss - a meta-analysis	https://www.biozentrum.uni-wuerzburg.de/zoo3/team/holzschuh/
Douglas Landis	15	USA	18	1253	Michigan State University	Landscape diversity enhances biological control of an introduced crop pest in the north-central USA	https://www.canr.msu.edu/people/doug_landis

(Tscharntke et al., 2012), which discussed the link between agricultural intensification, biodiversity and food security, summarized the major debate about land sparing and sharing and presented evidence that ecological agriculture can achieve high yields. The second, Ingolf Steffan-Dewenter, has published 33 articles in this field. His most highly cited article is "*Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance*" (Garibaldi et al., 2013). This study shows that wild insects and honey bees promoted fruit set independently, and therefore, the integrated management of honey bees and diverse wild insects can enhance global crop yields. The third is Claire Kremen, who is based at the University of California, Berkeley. A representative article of hers is "*Modelling pollination services across agricultural landscapes*" (Lonsdorf et al., 2009). This study provides a quantitative and mechanistic model to predict the pollinator abundance in a landscape. Including these three researchers, all the investigators are natural scientists, and they all focus on agroecology, landscape ecology or the relationship between land use, biodiversity and ES, etc. Moreover, some of these investigators try to collaborate with different disciplines to promote AES development.

3.1.4. Analyses of Subject Categories

The 3573 articles in this study were divided into 59 subject categories in the WoS (the list of categories can be found at http://images.webofknowledge.com//WOKRS529MR9/help/WOK/hs_research_domains.html#dsy5465-TRS_arts_humanities). As shown in Fig. 5, according to the categories of the WoS, we classified the subjects into the following five primary groups: Arts, Humanities & Social Sciences; Science & Technology (Life Sciences & Biomedicine); Science & Technology (Physical Sciences); Science & Technology (Technology) and Science & Technology (Other Topics). The results show that approximately 92% of the articles relate to Science & Technology. Environmental Sciences & Ecology (38.93%) is the most common category, followed by Agriculture (11.67%) and Biodiversity & Conservation (7.33%). In the Arts, Humanities & Social Sciences category, Business & Economics (3.01%) and Geography (2.46%) are the most common categories.

To observe the multidisciplinary integration of AES research, we analysed the subject categories of each article. As shown in Fig. 6, 77.5% of the 3573 articles pertained to single disciplines, 20.35% involved two disciplines and only 2.16% involved three disciplines. We can observe that the multidisciplinary integration between natural science and technology is extensive. The overlaps between Arts, Humanities & Social Sciences and Science & Technology (Life Sciences & Biomedicine) are relatively greater, at over a total of 216 articles. In conclusion, the AES researchers gradually engaged in the integration of multiple subjects, but natural science and technology are still the dominant subjects of AES research.

3.2. Research Themes

3.2.1. The most Frequently Cited Articles

A higher citation frequency indicates a higher impact article. Table 3 lists the information on the 10 most frequently cited articles from 2008 to 2017 in the AES field, such as the total referenced frequency, article titles, annual citations, author names, publication years, and journal titles. Specifically, *Ecology Letters* published 2 articles, and the others were published by different journals. The most highly cited article is entitled "*Economic valuation of the vulnerability of world agriculture confronted with pollinator decline*", which was authored by Gallai et al. (2009) and published in *Ecological Economics* in 2009, with 664 citations and 66.4 annual citations. The primary contribution of this study is that it calculates the economic value of pollinator contributions to food production and evaluates the vulnerability of global agriculture in the face of declining pollinators. The second-most highly cited article is "*Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance*" as authored by Garibaldi et al. (2013) in Science. The third
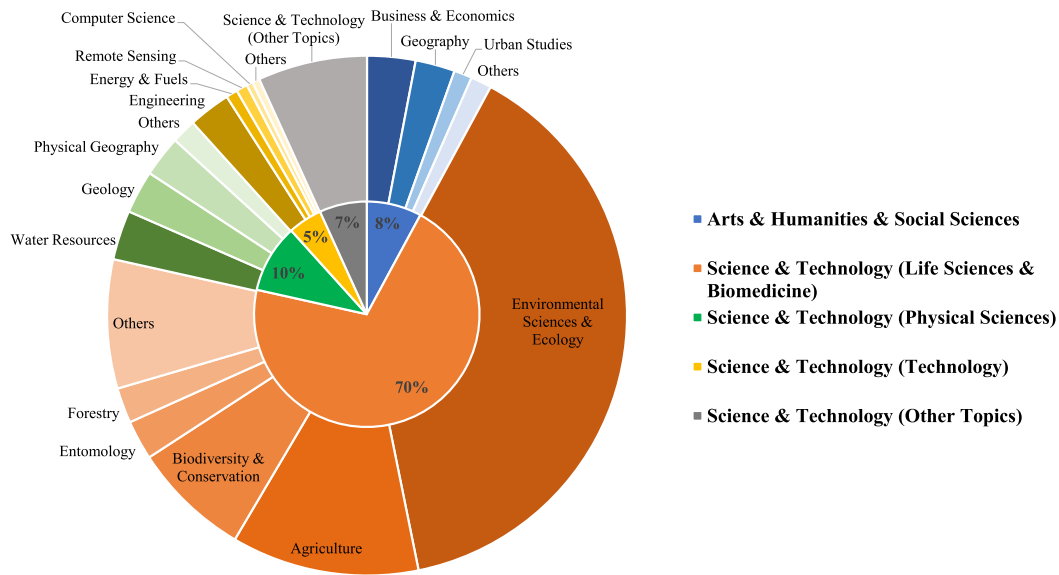
Fig. 5. Subject categories.

is "*Ecosystem service bundles for analyzing tradeoffs in diverse landscapes*" authored by Raudsepp-Hearne et al. (2010) in PNAS, and this study is based on the concept of ES bundles as developed from a framework to analyse the interactions between multiple ES across landscapes. In conclusion, the 10 most frequently cited articles primarily focus on biodiversity, including the relationships between biodiversity and landscape structures (Billeter et al., 2008; Fahrig et al., 2011), the effects of agricultural intensification on biodiversity (Flynn Dan et al., 2009; Tscharntke et al., 2012), the effects of pesticides on biodiversity (Geiger et al., 2010; Gill et al., 2012), and the effects of human disturbances on bees (Winfree et al., 2009).

3.2.2. The most Frequently Cited References

A cited reference analysis can provide more useful information on a specific research area, and the frequency of reference citations can reveal insights into the knowledge base of a field (Bornmann and Marx, 2014). Table 4 lists the basic information on these references. The most highly cited article is "*Landscape perspectives on agricultural*

intensification and biodiversity – ecosystem service management" authored by Tscharntke et al. (2005) in *Ecology Letters*. This article, which is from a landscape perspective, reviewed the effects of agriculture on biodiversity conservation, the potential mechanisms underlying the relationships between biodiversity and ES, and the role of biodiversity in multifunctional agriculture, and it presented an analysis on the importance of biodiversity to ES. In addition, it also proposed some suggestions for agri-environment schemes. The research with the second-highest number of citations is titled "*The value of the world's ecosystem services and natural capital*" as authored by Costanza et al. (1997) and published in *Nature* in 1997, with 336 citations. This study was the first to propose that ES provide a range of services, and they are the foundation of human existence. Moreover, it was the first to estimate the economic value of 17 ES in 16 biomes based on published studies and a few original calculations. Additionally, the MEA report has been cited 171 times, and this report provided a recognized ES classification system for collating, evaluating, summarizing, interpreting, and communicating the achievements of different scientific articles (Millennium
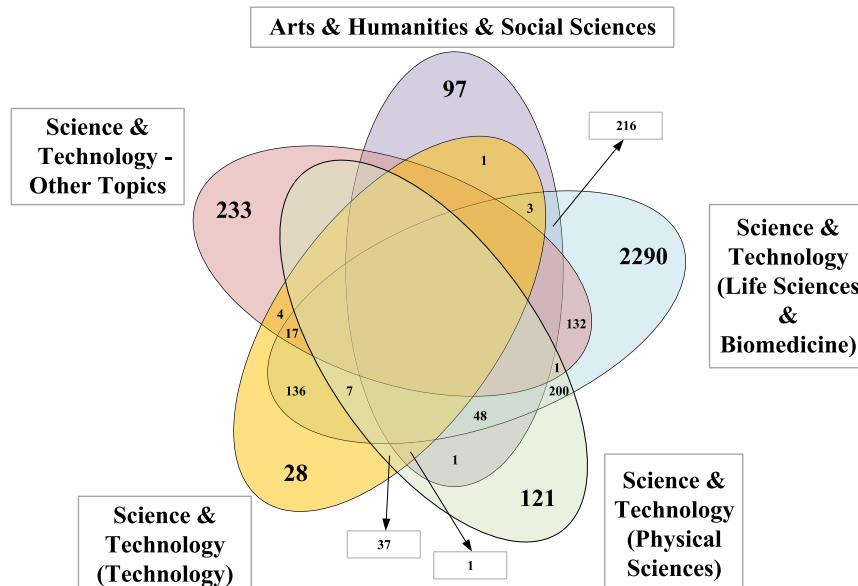

Fig. 6. Venn diagram of the different subjects.

Table 3
The 10 most frequently cited articles from 2008 to 2017.

Frequency	Annual citations	Article	Author	Year	Journal
664	66.4	Economic valuation of the vulnerability of world agriculture confronted with pollinator decline	Gallai, Nicola et al.	2009	Ecological Economics
529	88.17	Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance	Garibaldi, Lucas A. et al.	2013	Science
522	58	Ecosystem service bundles for analysing tradeoffs in diverse landscapes	Raudsepp-Hearne, C. et al.	2010	Proceedings of The National Academy of Sciences of The United States of America
474	67.71	Global food security, biodiversity conservation and the future of agricultural intensification	Tscharntke, Teja et al.	2012	Biological Conservation
436	54.5	Functional landscape heterogeneity and animal biodiversity in agricultural landscapes	Fahrig, Lenore et al.	2011	Ecology Letters
389	38.9	Loss of functional diversity under land use intensification across multiple taxa	Flynn, Dan F. B. et al.	2009	Ecology Letters
344	34.4	A meta-analysis of bees' responses to anthropogenic disturbance	Winfree, Rachael et al.	2009	Ecology
330	36.67	Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland	Geiger, Flavia et al.	2010	Basic and Applied Ecology
319	29	Indicators for biodiversity in agricultural landscapes: a pan-European study	Billeter, R. et al.	2008	Journal of Applied Ecology
292	41.71	Combined pesticide exposure severely affects individual- and colony-level traits in bees	Gill, Richard J. et al.	2012	Nature

Ecosystem Assessment, 2005). Therefore, a great deal of research based on the concepts of MEA reports was published (Hrabanski, 2017; Solazzo et al., 2015; Vaissiere et al., 2013). Most of the other papers are review articles, and they are primarily focused on trade-offs and synergies in ecosystem services and dis-services with agriculture (Power, 2010), describing, classifying the services and dis-services of AES (Zhang et al., 2007), the effects of land use changes (landscape diversity) on (agriculture) ES (Bianchi et al., 2006; Foley et al., 2005; Klein et al., 2007), quantifying ecosystem services and analysing trade-offs between them (Nelson et al., 2009) and reviewing the scientific and policy challenges involved in developing sustainable agriculture (Tilman et al., 2002).

3.2.3. The Most Frequently Used Keywords

We can filter out the primary messages of one paper using keywords, and a keyword analysis can identify the research themes of a research field (Hou et al., 2015). In this study, we analysed the author keywords of the 3573 articles, and there is a total of 8881 keywords. We pre-treated the original data to make the data more reasonable. Similar keywords, such as "Ecosystem services" and "ecosystem service"; "Land use change" and "Land-use change"; "Agroecosystem", "agroecosystems" and "agro-ecosystems"; and "Organic agriculture" and "organic farming" were merged. After a series of data management processes, there were a total of 7631 keywords, but most keywords appeared only once, and thus we selected the top 103 keywords with a frequency ≥ 19 to analyse. After excluding the words "Ecosystem services" (916 times) and "Agriculture" (209 times), the top 3 words were "Biodiversity" (243 times), "Land use change" (143 times) and "Climate change" (119 times).

3.2.3.1. Keyword Co-occurrence and Categorization.
As shown in Fig. 7, when excluding "agriculture", the most frequently co-occurring words with "ecosystem services" are "Biodiversity" (120 times), "Land use change" (65 times), "Pollination" (57 times), "Land use" (47 times) and "Trade-off" (43 times). The keywords were then classified into 7 categories for further analysis into (1) ecosystem and ecosystem functions; (2) biodiversity; (3) land use and landscape patterns; (4) climatic change; (5) agricultural and sustainable development; (6) integrated analysis, modelling and valuation; and (7) policies and programmes.

3.2.3.1.1. Ecosystem and Ecosystem Functions.
As shown in Fig. 7, the category (1) includes words about ecosystems (e.g., "Agroecosystem", "Grassland" and "Agroecology"), typical areas (e.g., "Europe" and "China") and functions (e.g., "Restoration" and "Resilience"). At present, the definition of ecosystem functions and ES gradually becomes clear (Costanza et al., 1997; Costanza et al., 2017). However, in understanding the connections among ecosystem functions, different ES and human well-being are not comprehensive, and the classification is still not uniform (Costanza et al., 2017). As a compound ecosystem system, the diversity of ecosystems, environmental conditions and human activities all have impacts on agroecosystems. In this sense, agroecosystem functions and services exhibit complicated variability across both space and time. Therefore, the study of AES and its functions has held the attention of numerous researchers in recent years.

3.2.3.1.2. Biodiversity.
The second category includes keywords related to pollination services (e.g., "Pollination", "Pollinator" and "Bee"), biological control (e.g., "Natural enemy") and biodiversity (e.g., "Species richness" and "Biodiversity conservation"). The development of an agroecosystem also relies on other services, such as pollination services, pest control and genetic resources (Garbach et al., 2014). In recent years, the importance of biodiversity in underpinning AES is well recognized. For example, pollinators play an important part in agricultural production and in providing pest control services (Aizen et al., 2009). Soil microbial diversity provides multiple services, such as improving the soil structure, driving the nutrient cycling and resolving

Table 4
The 10 most frequently cited references from 2008 to 2017.

Frequency	Article	Author	Year	Journal
355	Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management	Tscharntke et al.	2005	Ecology Letters
336	The value of the world's ecosystem services and natural capital	Costanza et al.	1997	Nature
294	Global Consequences of Land Use	Foley et al.	2005	Science
225	Ecosystem services and agriculture: trade-offs and synergies	Power A	2010	Philosophical Transactions of the Royal Society B: Biological Sciences
223	Importance of pollinators in changing landscapes for world crops	Klein et al.	2007	Philosophical Transactions of the Royal Society B: Biological Sciences
192	Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest control	Bianchi et al.	2006	Philosophical Transactions of the Royal Society B: Biological Sciences
184	Ecosystem services and dis-services to agriculture	Zhang et al.	2007	Ecological Economics
175	Modelling multiple ecosystem services, biodiversity conservation, commodity production, and trade-offs at landscape scales	Nelson et al.	2009	Frontiers in Ecology and the Environment
171	Ecosystems and Human Well-being: Current state and trends	Millennium Ecosystem Assessment	2005	–
154	Agricultural sustainability and intensive production practices	Tilman et al.	2002	Nature

the organic matter (Bender et al., 2016). However, many studies have shown that the dis-services of agricultural are one of the factors that have led to biodiversity losses (Erisman et al., 2016; Klein et al., 2007). Therefore, the relationship of biodiversity to agricultural development has attracted attention from scholars, governments and various non-governmental organizations (NGO).

3.2.3.1.3. Land use and Landscape Patterns. This category includes keywords about land use and land cover changes (e.g., "Land sparing" and "Land sharing") and landscapes (e.g., "Landscape complexity" and "Landscape ecology"). Studies have shown that different land use types provide different types of ES (Burkhard et al., 2009; Tsiafouli et al., 2015). In addition, assessing land cover change effects on biodiversity and ES has been given attention, such as farmland reductions caused by urbanization, deforestation caused by agricultural expansion and

others. Two models have been proposed to maximize the services and minimize the dis-services as "land sparing" and "land sharing". The debate on land sharing/sparing is continuous and has become polarized, but these approaches are still effective under certain circumstances (Baudron and Giller, 2014; Bennett, 2017). Agriculture is a major beneficiary of ES, depending on other ecosystems at a large scale. Therefore, there is growing concern about the effects of AES caused by agricultural activity at landscape scales. Some views show that landscape complexity can enhance services from biodiversity in some cases (Tscharntke et al., 2005; Zhang et al., 2007). Consequently, agricultural management should not only consider the single fields but also include the surrounding landscape (Roschewitz et al., 2005).

3.2.3.1.4. Climatic Change. This category includes keywords about the carbon cycle (e.g., "Carbon sequestration" and "Soil carbon"),
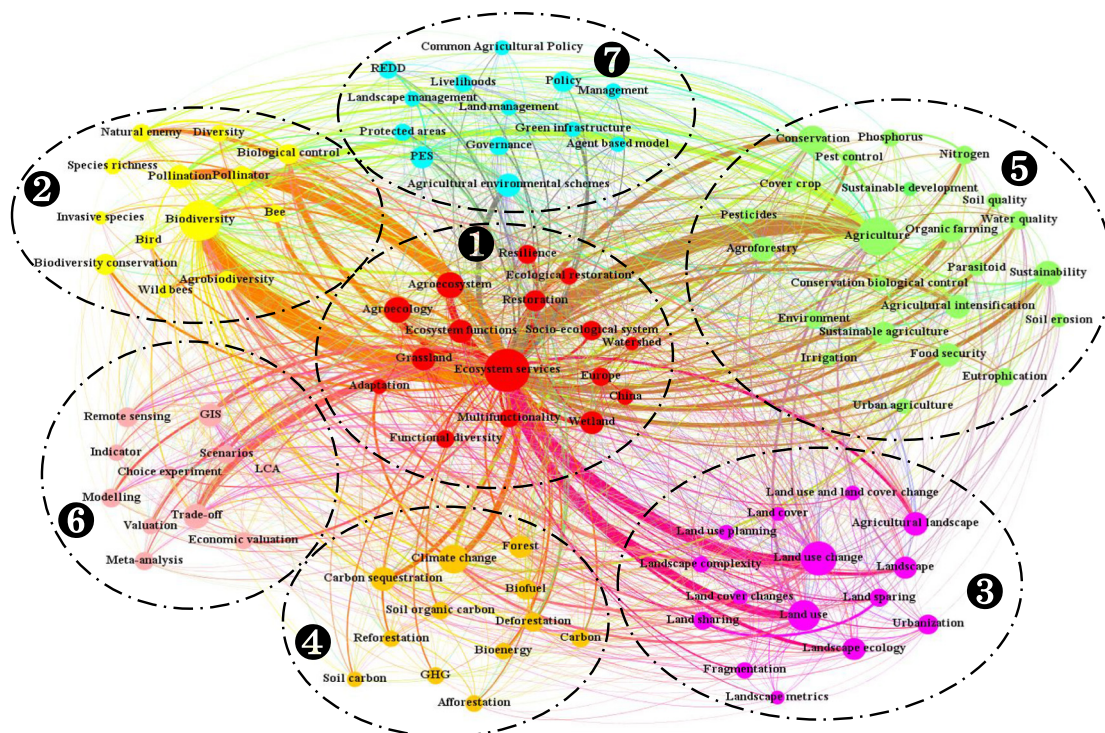
❶ **Ecosystem and ecosystem functions;** ❷ **Biodiversity;** ❸ **Land use and landscape patterns;** ❹ **Climatic change;** ❺ **Agricultural and sustainable ;** ❻ **Integrated analysis, modelling and valuation;** ❼ **Policies and programmes**

Fig. 7. The network of the 103 most frequently occurring keywords (frequency ≥ 19).

agriculture & forestry (e.g., "Reforestation" and "Forest") and biofuel/bioenergy. The interactive relationship between agriculture and climatic change is complex. Climatic change is increasingly affecting ecosystems and their services (Calzadilla et al., 2014; Warren et al., 2011). Agriculture is one of the most sensitive and fragile fields in relation to climate change, and any degree of climate change would have potential and significant effects on agricultural production and its related processes. However, the agroecosystem plays a small but significant role in the overall global carbon cycle (Post et al., 2004). Agricultural production (chemical fertilizer and ploughing, etc.) can lead to various direct greenhouse gas (GHG) emissions (Kahrl et al., 2010; Vermeulen et al., 2012). By contrast, some studies suggest that the agriculture sector has the potential to reduce GHG emissions (Jones et al., 2013; Nimkar et al., 2015). It is widely accepted that minimal and no tillage, straw return and organic fertilizer will increase carbon sequestration in soil (Muller, 2012; Wüstemann et al., 2017). Furthermore, agriculture is a major driver of deforestation, and deforestation is one of the indirect GHG emissions sources of the food system (Vermeulen et al., 2012). Therefore, there are many studies on the relationships among agriculture, forests and climatic change. Additionally, in the face of climate change, some studies have called for the use of bioenergy to reduce life-cycle GHG emissions by offsetting fossil fuels. However, whether such land cover changes will have potential influences on ecosystem or economic-social factors has been the subject of widespread concern (Campbell et al., 2008; Kumar et al., 2009; Mladenoff et al., 2016).

3.2.3.1.5. Agricultural and Sustainable Development. This category includes keywords about the services to agriculture (e.g., "Pest control", "Nitrogen" and "Phosphorus"), dis-services from agriculture (e.g., "Soil erosion" and "Eutrophication") and agricultural practices (e.g., "Agroforest", "Cover crop" and "Agricultural intensification"). To meet the population's food needs in the future and protect the environment, various negative environmental and social effects caused by modern agricultural practices have received substantial attention (Hunter et al., 2017; Kumar et al., 2005; Wu et al., 2018; Yan et al., 2017). Therefore, to minimize the dis-services, farmers must use less chemical fertilizers and pesticides, change land use patterns and adopt farming practices that mimic natural ecological processes. Although there is much discussion concerning the contribution of organic farming to agricultural productivity, the scientific management of organic farming will reduce or eliminate the yield gap between organic farming and conventional agriculture (Ponisio et al., 2015; Röös et al., 2018; Schrama et al., 2018; Wüstemann et al., 2017). At present, many organic agriculture practices are already generally used and accepted on a global scale, such as no-till, multispecies cover crops, crop rotation, terrace cultivation, biological control, etc.

3.2.3.1.6. Integrated Analysis, Modelling and Valuation. This category includes the keywords pertaining to the methods (e.g., "GIS" and "Meta-analysis") and research objects (e.g., "Valuation" and "Economic valuation"). There is a reciprocal or synergic relationship between different ES. Therefore, to mitigate conflicts and identify optimal decision points, trade-offs are required and have recently been made (Deng et al., 2016; Turkelboom et al., 2016). Especially in agricultural production systems, an ES trade-off analysis can help to identify optimal agricultural management strategies to prevent or mitigate negative environmental effects (Li et al., 2017). Within this framework, valuation is an inevitable and useful way to help assist with manager trade-offs and for making decisions (Costanza et al., 2017). Since 1997, there has been increasing interest in estimating the monetary value of ecosystem services, and there are now various tools for monetary valuation (Costanza et al., 1997; de Groot et al., 2012; Porter et al., 2009; Xie et al., 2017). For example, choice experiments (CE) are a stated preference method for valuing non-market services, and they have been widely used in recent years (Colombo et al., 2013; Kenter et al., 2011). Additionally, with the

development of computer technology, geographic information systems (GIS), remote sensing (RS), and integrated modelling, the analysis of ES has attracted considerable attention from AES researchers in recent years (Li et al., 2014). Integrated modelling can apply in various scenarios and can help the policymaker to make decisions (Burkhard et al., 2013). Therefore, researchers have focused on applying integrated, spatial and dynamic models to improve the accuracy and reliability of complicated ES research recently (Shoyama et al., 2017).

3.2.3.1.7. Policies and Programmes. In contrast to other ecosystems, the primary service of agroecosystems is food production. Therefore, an urgent task is to determine how to ensure improvements in food production while protecting the functions of agroecosystems. It is easy to understand how human activities have altered ecosystems and biodiversity. Conversely, the ways in which changes in ecosystems and biodiversity can impact human welfare also deserve some attention. In general, various studies to assist in making human decisions vis-à-vis ecosystems are necessary.

There are two levels of agroecosystem regulation and control. One is direct management by human activities (such as land use change and agricultural practice changes) and one is the indirect regulations provided by policies that can deeply affect human behaviour (such as a subsidy). Payment for environment/ecosystem services (PES) is an effective ecological system management approach based on a market mechanism. In addition, PES schemes have become intermediaries of the government between those who benefit and those who preserve the ecosystem services. As a useful policy instrument, PES can be used to enhance the supply of services from agroecosystems or reduce deforestation caused by agriculture production (Aslam et al., 2017; Vorlaufer et al., 2017). PES schemes have been widely applied all over the world in recent years (Aslam et al., 2017; Guo et al., 2018). In facing deforestation and climatic change, the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD) programme and China's Grain for Green programme were proposed. These programmes are committed to restoring forest landscapes or developing agroforestry. In addition, there are many projects that refer to the recovery and protection of AES all over the world, such as Agri-environment schemes, Common Agricultural Policy, and the Integrated Modern Agriculture Development Project. All these projects have contributed to the development of sustainable agriculture.

3.2.3.2. Keyword Evolution in Two Periods (2008–2012 and 2013–2017). There are many projects that have referred to ES all over the world since 2008. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an influential intergovernmental body, and its mission is to "strengthen knowledge foundations for better policy through science, for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development" (IPBES, 2012). Consequently, we divided the development of AES themes into two periods, 2008–2012 and 2013–2017. As shown in Fig. 8, "Ecosystem and ecosystem functions" and "Agricultural and sustainable development" are always the primary research themes during the two periods, and the keywords about these two themes account for more than half of the total. Except for "ecosystem and ecosystem services" and "Biodiversity", the proportion of the other themes has increased or is invariable. In particular, the keywords about "Biodiversity" were clearly reduced, from 15% to 11%, while "Land use and landscape patterns" increased from 10% to 13%.

The 20 most frequently used keywords during the two periods are shown in Fig. 9, which can provide an overview of the evolution of keywords during the last decade. In terms of frequent use, "Land use change" increased the most, from 30 times during the 2008–2012 period to 130 times during the 2013–2017 period. The next is "Biodiversity" from 90 to 180. In terms of growth rates, the frequency of "Land use change", "Agroecology" and "Trade-off" increased over four-fold. The frequency of "Climate change", "Food security" and "Land
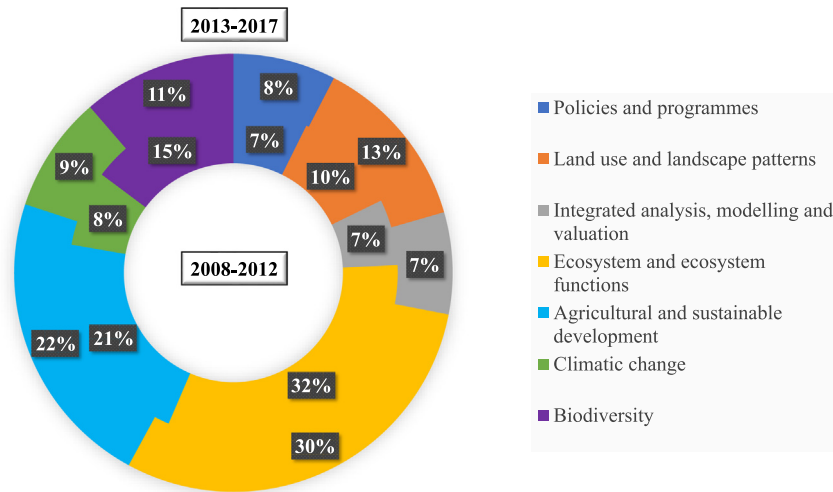
Fig. 8. The characteristics of 7 themes from different periods.

use" increased over three-fold. These changes suggested that these keywords gained popularity in the past five years.

4. Discussion

4.1. Research Key Themes: Biodiversity and Land Use

The keywords relating to frequency analysis have revealed that the primary themes focused on "biodiversity" and "land use", and the analysis of the most frequently cited articles also confirm this finding. According to Fig. 9, we can find that the "Biodiversity" words are always the most frequently appearing keywords during the two periods. Agrobiodiversity involves many aspects, including the variety and variability of animals, plants and microorganisms that are necessary for sustaining key functions of the agroecosystem (Shen et al., 2017). There is a great deal of discussion about the interactive relationship between biodiversity and ES from qualitative and quantitative perspectives, but the specific mechanisms that connect them are not well understood at present (Aldana-Domínguez et al., 2017; Cardinale et al., 2012). Moreover, the multilayered relationship of biodiversity and AES indicates that managing one will automatically influence the other (Mace et al., 2012). Consequently, it is crucial to investigate how biodiversity fits into the practical application of AES and how to trade off its services. Accordingly, agrobiodiversity will still be the key theme in the future.

Furthermore, according to Figs. 8 and 9, we can observe that the

studies referring to "land use" rapidly decreased during the 2013–2017 period. Ecosystem transformations caused by human land use activities have produced extensive and profound influences on the agroecosystem. The agriculture system is a human-dominated ecosystem; it has a simple ecological structure, and the material cycle path is shortened. Accordingly, land use and landscape management are the most effective and efficient ways to influence the ES (Foley et al., 2005; van den Belt and Blake, 2014). From farmland level, optimum land use practices can make good use of the natural process and minimize the negative impacts on the environment. For example, rice-fish farming in Asia provides multifunctional goods and services, such as the prevention of malaria, the conservation of biodiversity, pest regulation and water conservation and restoration (Min et al., 2009). From a broader landscape viewpoint, the landscapes that lie beyond farm boundaries are also important to local farmland, for reasons such as providing habitats for pollinators. Previous research has shown that the distance between coffee farms and forests plays an important role in pollination services and has a direct influence on the yield and quality (Priess et al., 2007). Therefore, one of the key restricted factors is how to protect and utilize land resources effectively at different scales, and it will still be among the key themes of the future.

4.2. Valuation Is Indispensable, but the Need Goes Beyond Monetary Valuation

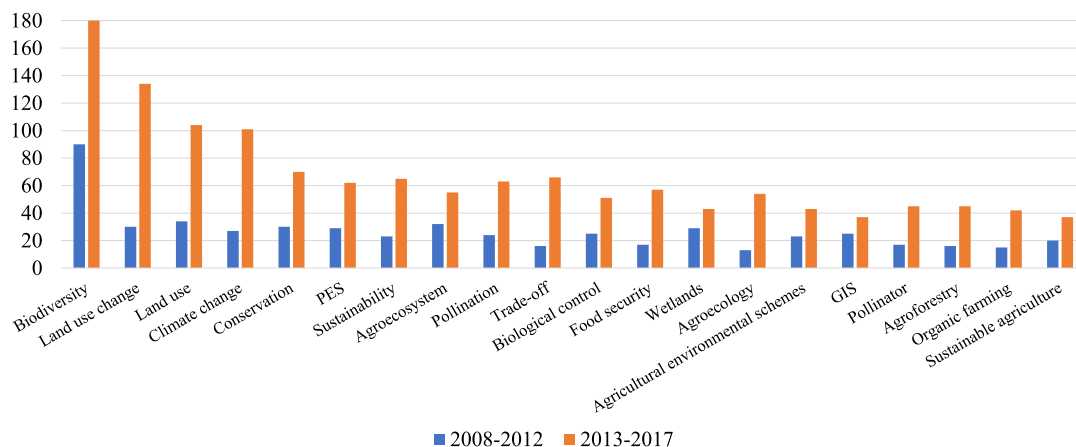A comprehensive valuation can provide critical information to

Fig. 9. The 20 most frequently used keywords during the two periods (except "ecosystem services" and "agriculture").

support decision-making in the management of agroecosystems. Monetary valuation has attracted a great deal of attention in the ES field (Baveye et al., 2013; Costanza et al., 2017; D'Amato et al., 2016), and the most frequently cited articles in this study from the last decade are also about monetary valuation. However, according to the keywords analysis in this study, monetary valuation is not so common. There may be two reasons, (1) research on the monetary valuation of AES did not have a unified keyword. The author keywords are varied, such as "Economics", "Economic value" and "Market value". Therefore, the statistical analysis of the popular keywords did not include many keywords that referred to the monetary valuation. (2) It is generally known that the ES values of agroecosystems (except the production function) are lower than those of other natural ecosystems (van den Belt and Blake, 2014). Moreover, the agroecosystem is influenced and restricted by manifold factors (especially human activities), and the agricultural ecosystem exhibits complicated variabilities over both space and time. In this sense, all these facts increase the difficulties in valuation. Therefore, these factors may affect progress in the monetary valuation of AES research.

The goal of AES research is to translate the science into actual policy decisions. In practice, decision-making always involves several factors, such as the scale, time, culture, participator and objects. Therefore, valuation cannot be limited to money, and an integrated valuation that includes the ecological, social and cultural value is imperative. Therefore, the valuation of an AES requires more participation from multidisciplinary scientists. In the future, developing a valuation framework that combines monetary and non-monetary valuations as well as a trade-off analysis, including an agroecosystem's functions, benefits, and values that can support policymaking is the future trend in AES research.

4.3. Agroecosystem Services: An Integrative Research Field

The agroecosystem is a complex system, and therefore, AES research must be integrated with knowledge from diversified subjects. According to the analysis, the AES concept has been received by scholars in various fields, although natural scientists are still the major contributor. In practice, no single dimension can contribute to our holistic understanding of AES and help managers to make decisions about the improvement and maintenance of AES. Therefore, AES management will require support from many subjects including agricultural ecology, geography, economics, environmental science and social science. In conclusion, the existing studies have laid a firm foundation for the further multidisciplinary integration of AES research and multidisciplinary integrative research, and using them for understanding, modelling, evaluating, and managing the AES will be a trend in the near future.

4.4. Problems and Research Limitations

In this study, the index words are "agriculture" and "ecosystem service" (and variations in their spellings). Agriculture is a comprehensive concept, and some researchers may be using "farm", "crop", "fruit" and "livestock" as keywords. However, to avoid obtaining search responses that were unrelated to the theme, we only analysed research articles within strict limitations. Furthermore, there are different synonyms for "ecosystem services", such as the ecosystem function, environment services and others (strictly speaking, these words have different meanings, but some other field researchers may be confused). Previous studies showed that the field was dominated by "ecosystem services" since 2007 (Tancoigne et al., 2014). Therefore, we did not consider other synonyms. Finally, some of the keywords do not have practical significance, and therefore, their categorization in Section 3.2.3 will have potential bias. For example, "Diversity" may be derived from "biological diversity", "ecosystem services diversity" or "land use diversity". To overcome this problem, we put this term in the category

that has the highest collaboration frequency.

However, there are still some limitations to this study. First, due to the language limitation of the study, some excellent non-English articles were not captured by this analysis. Thus, the contribution of non-English speaking countries will be undervalued. Secondly, some excellent papers that did not use the related keywords were not captured in this study. Thirdly, future research should cover other databases as well, such as Scopus or Google Scholar, to validate the findings of this study. Finally, the bibliometric method was not used to analyse the contents of the papers, and therefore, this study could be complemented by a deeper analysis.

5. Conclusions

This study utilizes a bibliometric approach to review the publication performances and research themes within the AES field both quantitatively and qualitatively. Based on the WoSCC database, there were a total of 3573 records related to AES during the 2008–2017 period. The number of annual publications exhibited an increasing trend during this period. *Agriculture, Ecosystems & Environment* has published the most articles in the AES field. At the global scale, there are 14 countries that have published more than 100 articles in this field that exhibited a high level of collaboration with other countries/territories. The three most influential authors are Teja Tscharntke, Ingolf Steffan-Dewenter and Claire Kremen. The studies within the AES field refer to both Arts, Humanities & Social Sciences subjects and Science & Technology subjects. According to a research themes analysis, we have identified the following 7 popular themes: ecosystem and ecosystem functions; biodiversity; land use and landscape patterns; climatic change; agricultural and sustainable development; and integrated analysis, modelling and valuation and policies and programmes. "Biodiversity" and "land use" are the most popular keywords and are the key themes in the AES field as well. Valuation is indispensable, but AES research has applications beyond monetary valuation. In conclusion, it cannot be denied that AES has been an integrative research field, and the field has gradually shifted from the traditional content, classification and theoretical research to the analysis of multiple spatial and temporal scales, different service trade-offs and synergies, dynamic evolution process analyses and other more systematic and diverse topics.

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